



Benchmark Analysis for Space Radiation Transport Codes in Thick Shielding for GCR Environments

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Outline

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- Simulation setup
- Results
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Background

- Updates to HZETRN revealed a minimum in the dose equivalent versus aluminum response curve
 - Mainly driven by neutron build-up in thick shielding in front of and behind target
 - Pion and electromagnetic cascade also contributes
 - Changes long standing shield design paradigm
- A program is underway to verify and validate this minimum
 - Verification: comprehensive and detailed benchmark calculation with transport models
 - Validation: thick shield experimental effort being conducted at NSRL
 - Both efforts are feeding into an uncertainty quantification effort that will inform risk assessment and probabilistic design



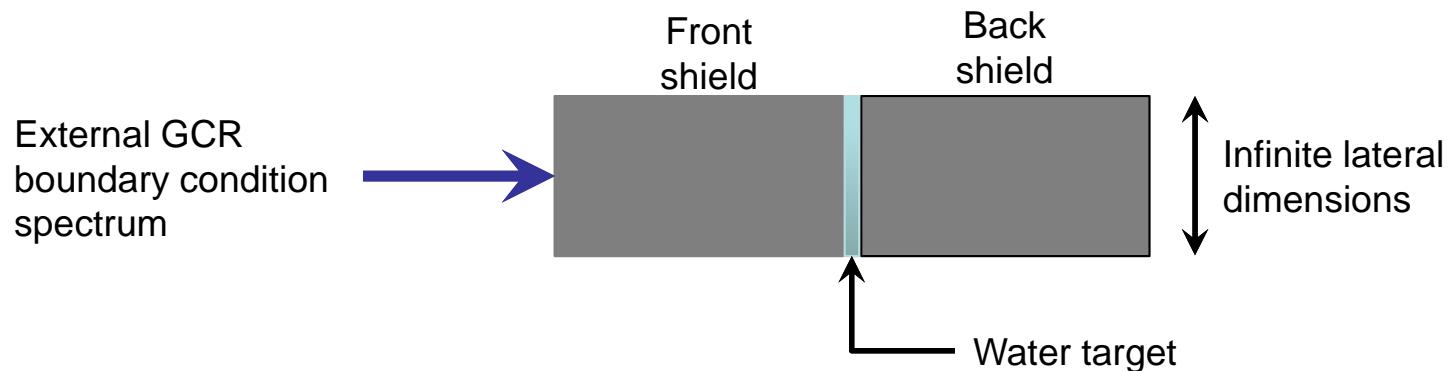
Background

- Previous benchmarks have been limited by computational resources
 - Monte Carlo simulations are computationally expensive
 - Comparisons typically focused on a limited set of shield configurations and inputs
 - Output quantities not always carefully aligned in Monte Carlo results
- Current set of benchmarks are more detailed and comprehensive than previously performed
 - Range of aluminum shield thicknesses being evaluated
 - “Important” components of the GCR environment considered separately
 - Range of output quantities (flux, dose, dose equivalent, LET spectra) being examined
- FY2015 benchmarks required ~100 years of CPU time (simple geometry)
 - 4 Monte Carlo codes run at LaRC and JSC on three different clusters
 - HZETRN results run on a desktop PC in minutes



Simulation Setup

- Slab with equal thickness of shielding in front and behind a thin (0.03 mm) water target
 - Considered a range of thicknesses from 0 g/cm² to 100 g/cm²
 - Aluminum and polyethylene considered as shielding materials
- 1977 solar minimum GCR environment boundary condition
 - Considered each ion individually with greater emphasis on more abundant ions
 - Connects with ions considered in measurement phase of project





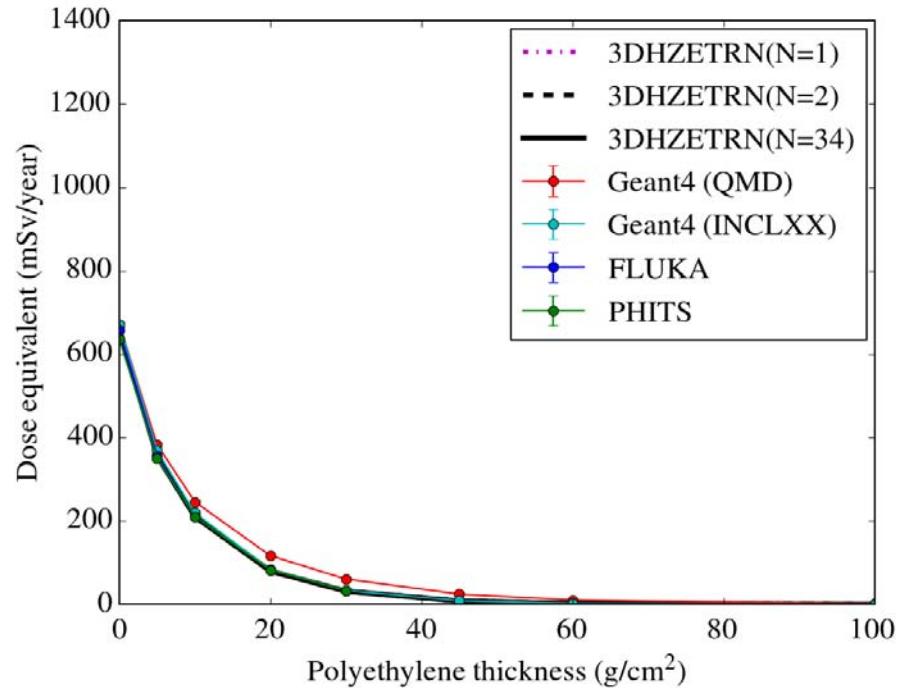
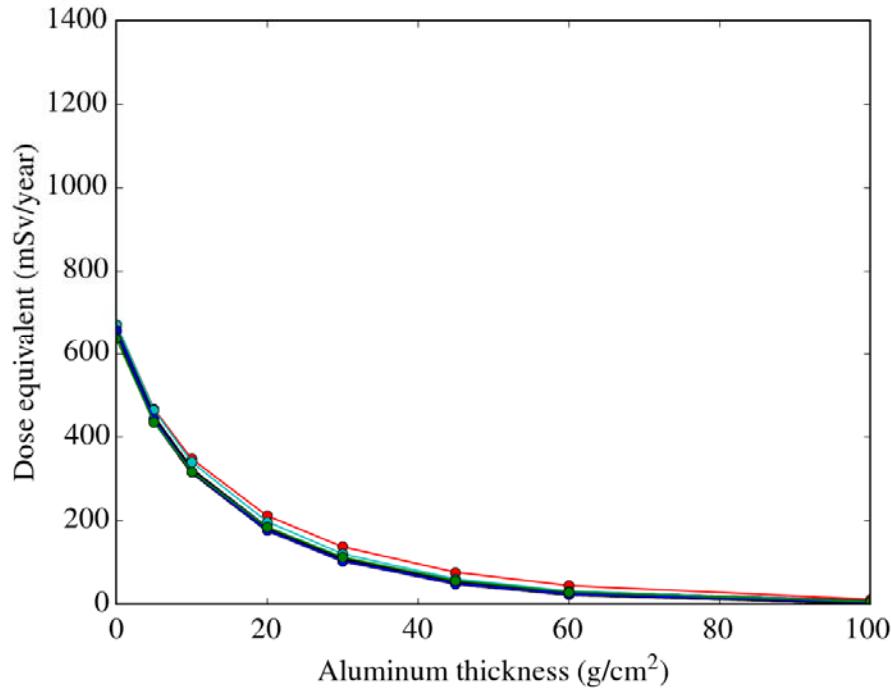
Simulation Setup

- Utilized 3 Monte Carlo codes along with most recent version of HZETRN
- Geant4, FLUKA, PHITS
 - Utilized 2 different heavy ion physics packages in Geant4 (QMD and INCLXX)
 - Essentially like having an extra Monte Carlo code
- 3DHZETRN
 - Evaluated 3 different levels of physical transport approximations
 - N=1: Straight-ahead approximation
 - N=2: Bi-directional
 - N=34: 3D treatment for neutrons and light ions



Results

Dose equivalent from $Z > 8$ for the full GCR boundary condition

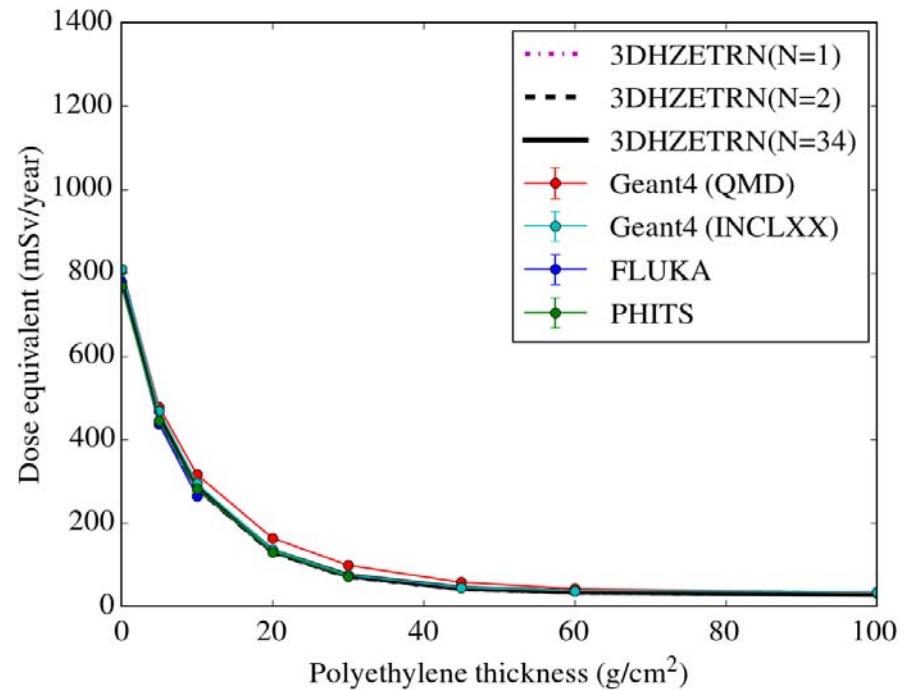
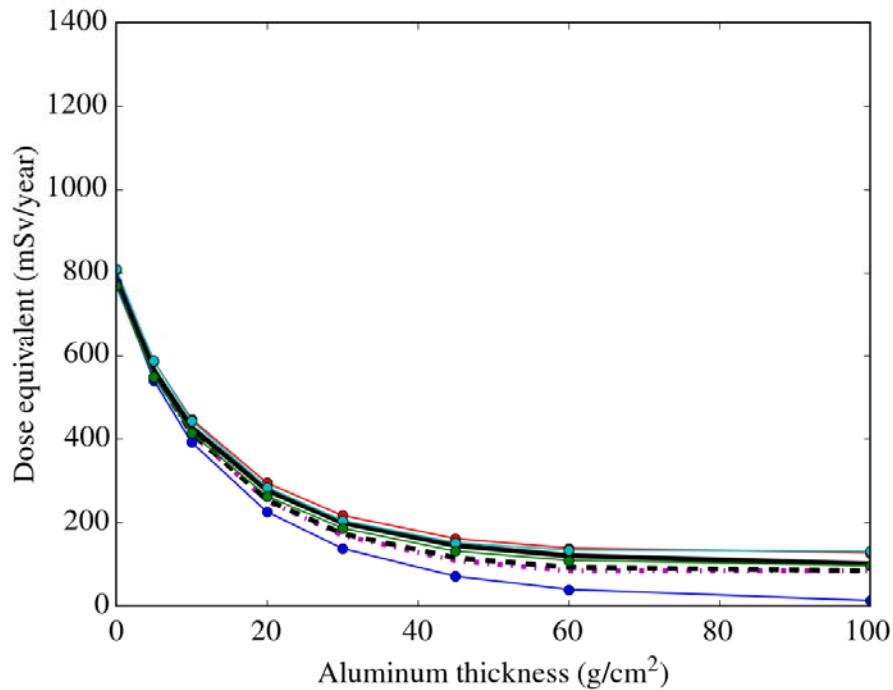


- Codes in very good agreement for heavy ions with $Z > 8$
 - Includes primary heavy ions and heavy projectile fragments
 - Excludes target fragments and light particles (neutrons and $Z \leq 2$)
 - Variation is driven by heavy ion nuclear physics model uncertainty



Results

Dose equivalent from $Z > 2$ for the full GCR boundary condition

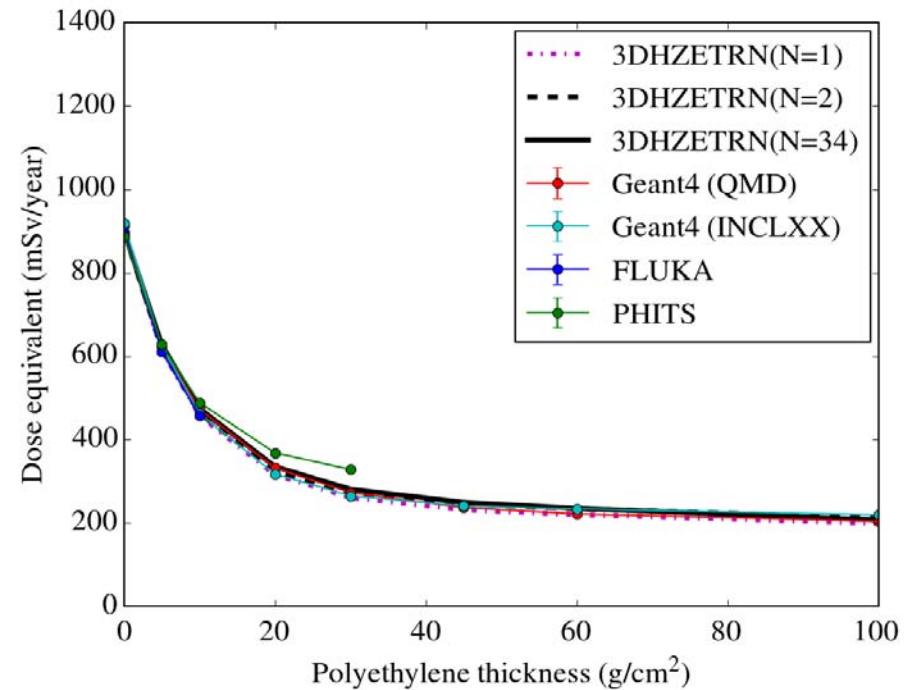
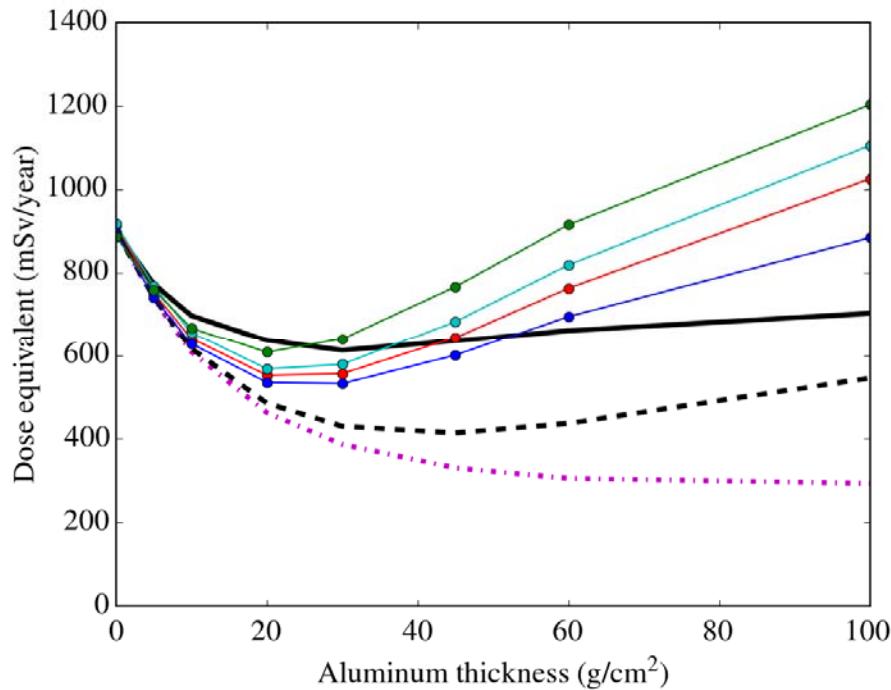


- Heavy target fragments ($Z = 3-8$) increase variation in code results
 - Includes primary heavy ions, heavy projectile fragments, and heavy target fragments
 - Variation appears to be larger for aluminum than polyethylene
 - Variation is still driven mainly by nuclear physics model uncertainty



Results

Dose equivalent from neutrons and ions for the full GCR boundary condition

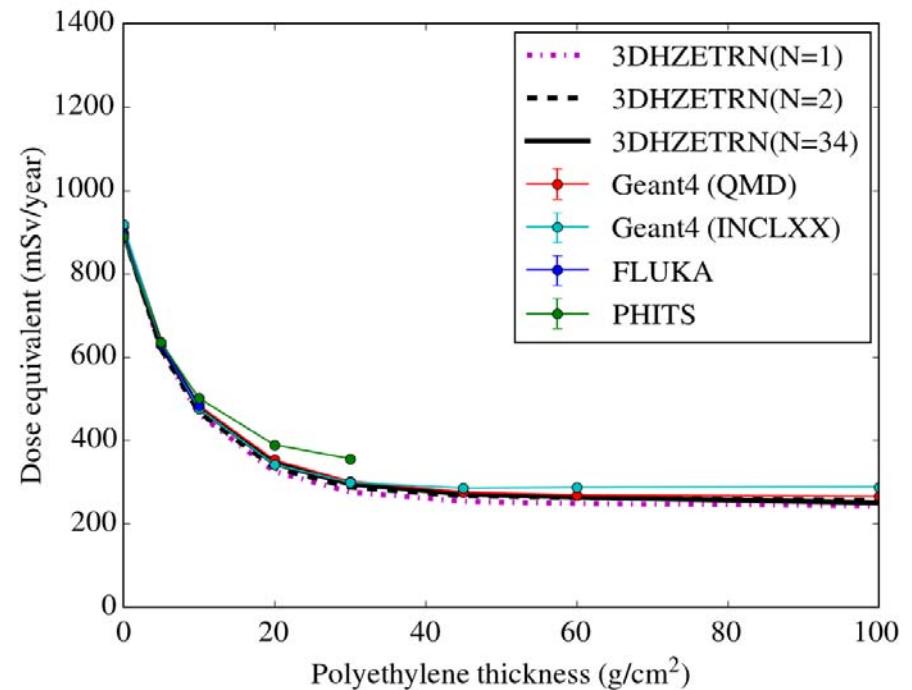
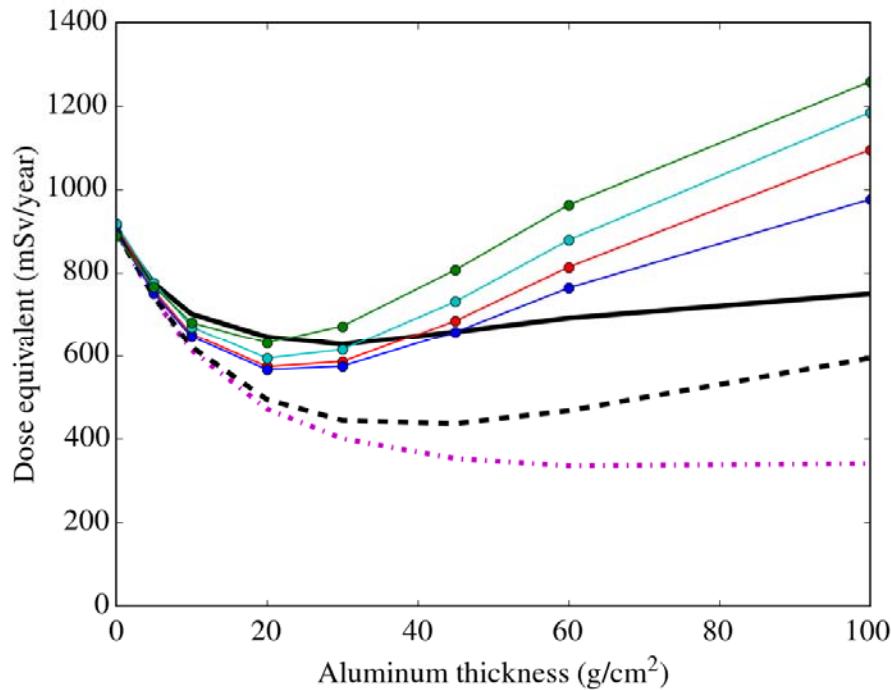


- Local minimum in aluminum shielding curve now apparent with neutron and light ions ($Z \leq 2$)
 - Includes everything except pion, muon, and electromagnetic components
 - 3D transport errors clearly visible
 - Variation is mainly driven by uncertainty in light ion production models



Results

Total dose equivalent for the full GCR boundary condition

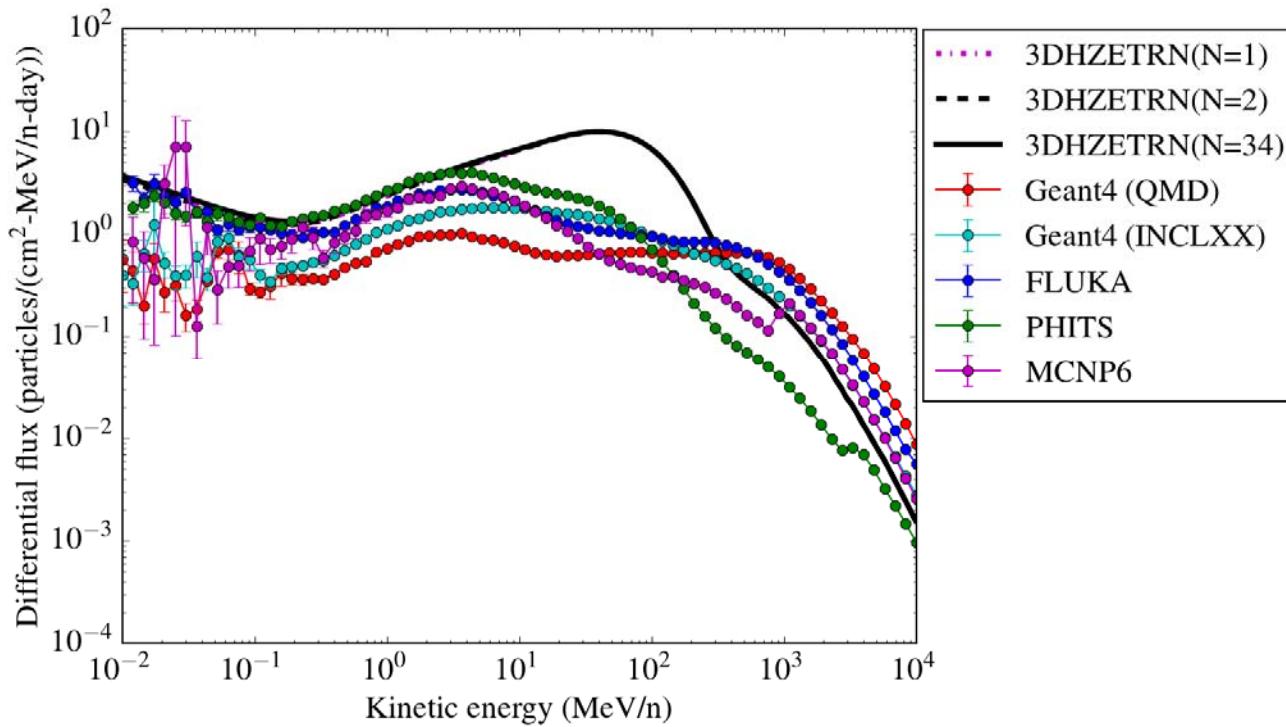


- Monte Carlo codes showing deeper minimum in aluminum than 3DHZETRN
 - Minimum and variation would be suppressed in finite geometry with tissue shielding
 - Local minimum is shifted closer to $20 \text{ g}/\text{cm}^2$ instead of $40 \text{ g}/\text{cm}^2$
 - Measurements plan has been adjusted accordingly



Results

^3He flux behind 20 g/cm^2 aluminum shielding for the full GCR boundary condition



- Large variation in secondary light ion fluxes (^2H , ^3H , ^3He)
 - Neutrons and protons do not show significant variation
 - Alphas show some variation, but not as large as ^2H , ^3H , ^3He
 - Measurements focusing on light ion production (energy and angle)



Conclusions

- Updates to HZETRN revealed a minimum in the dose equivalent versus aluminum response curve
- A program is underway to verify and validate this minimum
 - Initial verification results were presented
- Both 3DHZETRN and Monte Carlo codes show a minimum in the dose equivalent versus aluminum thickness curve near 20 g/cm^2
 - Large model uncertainties for light ion production
 - Nucleon and light ion production are the main contributors to the build-up in exposure beyond the minimum
 - Benchmark results are helping to guide and focus ongoing development of 3DHZETRN